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A MARKET ANALYSIS ON THE IMPACT OF ADDITIVE LAYER MANUFACTURING TECHNOLOGIES ON AEROSPACE AND DEFENSE SUPPLY CHAIN

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ABSTRACT

The manufacturing technologies are undergoing industrial revolution, primarily by significant advances in additive layer manufacturing (popularly known as 3D Printing) technologies. Instead of taking material out through conventional processes one builds desired parts by precisely adding one layer over another. This results in parts that are lighter, have almost zero wastage and afford flexibility to design parts not possible to manufacture using conventional technologies. Using this technology, the parts can be manufactured close to where they are needed and when they are needed. This can have significant impact on global supply chain operations, inventory control, labor arbitrage in the manufacturing sector, remanufacturing, and parts management. The technology significantly impacts the supply chain evolution by means of demand uncertainty, logistics optimization, increased flexibility, increased responsiveness, and required inventory reduction for production. Supply chain disintermediation, customer empowerment, co-creation and mass customization are other benefits. This paper describes about the technology of additive layer manufacturing and its relevance to

supply chain. It also provides the existing and potential future stakeholders. It provides the key factors which are influencing the business case of additive layer manufacturing on aerospace and defense supply chain. It explains the drivers of supply chain operations in terms of economic factors, resource, raw material, machine, tooling, quality, scaling, distribution and maintenance support. It also describes the trends on changes in sourcing & supply chain due to additive layer manufacturing in other industry sectors. It provides the technical, legal, financial and political implication assessment. It explains about the competitor footprint and extent of adoption of technology. It concludes the analysis of the impact of additive layer manufacturing technologies on aerospace and defense supply chain.

Key words: Additive Layer Manufacturing, Aerospace and Defense, Breakeven Analysis, Computer Aided Design, 3D Printing, Fused Deposition Modelling, Selective Laser Sintering, STereoLithography, Supply Chain, SWOT Analysis, Technology Maturity Curve, Technology Readiness Levels

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1. INTRODUCTION

The manufacturing technologies are undergoing industrial revolution, led primarily by significant advances in Additive Layer Manufacturing (ALM) (popularly known as 3D Printing, 3DP). The first industrial revolution is the mechanization of the textile industry, tasking previously done laboriously by hand to the cotton mill. The second industrial revolution is the moving assembly line to mass production. Now, the third industrial revolution is taking material out through conventional processes to builds desired parts by precisely adding one layer over another. This results in parts that are lighter, have almost zero wastage and afford flexibility to design parts not possible to manufacture using conventional technologies [1].

Using this ALM technology, the parts can be manufactured close to where they are needed and when they are needed. This can have significant impact on global supply chain operations, inventory control, labor arbitrage in the manufacturing sector, remanufacturing, and parts management. The technology significantly impacts the supply chain evolution by means of demand uncertainty, logistics optimization, increased flexibility, increased responsiveness, and required inventory reduction for production. Supply chain disintermediation, customer co-creation, customer empowerment and mass customization are other benefits.

In this paper, sections are organized as follows: Section 1, Introduction. Section 2, The Impact of Additive Layer Manufacturing Technologies on Aerospace and Defense Supply Chain. Section 3, Existing and Potential Future Stakeholders in Additive Layer Manufacturing Technology. Section 4, Key Factors Influencing the Business Case of Additive Layer Manufacturing Technology on Aerospace and Defense Supply Chain. Section 5, Key Drivers of Additive Layer Manufacturing Technology on Aerospace and Defense Supply Chain. Section 6, Trends on Changes in Supply Chain due to Additive Layer Manufacturing Technology. Section 7, Trends on Changes in Supply Chain due to Additive Layer Manufacturing Technology in Industry Sectors. Section 8, Case Studies of Additive Layer Manufacturing Technology on Aerospace and Defense Supply Chain. Section 9, The Competitor Footprint and Its Extent of Adoption of Additive Layer Manufacturing Technology in Aerospace and Defense Industry. Section 10, SWOT Analysis and Indicators of Future Growth. Section 11, Conclusions.

2. THE IMPACT OF ADDITIVE LAYER MANUFACTURING TECHNOLOGIES ON AEROSPACE AND DEFENSE SUPPLY CHAIN

This section explains about the impact of ALM technologies on the aerospace and defense supply chain in detail.

The ALM is a process of manufacturing technique that creates an object from electronic design file (3D model) such as STL (Stereo Lithography) file using Computer Aided Design (CAD), the software model into cross-sectional layers until the final object emerges, using raw materials such as metals, titanium powder, polymers, plastics and composites [2].

The ALM process flow, is as shown in Fig. 1.

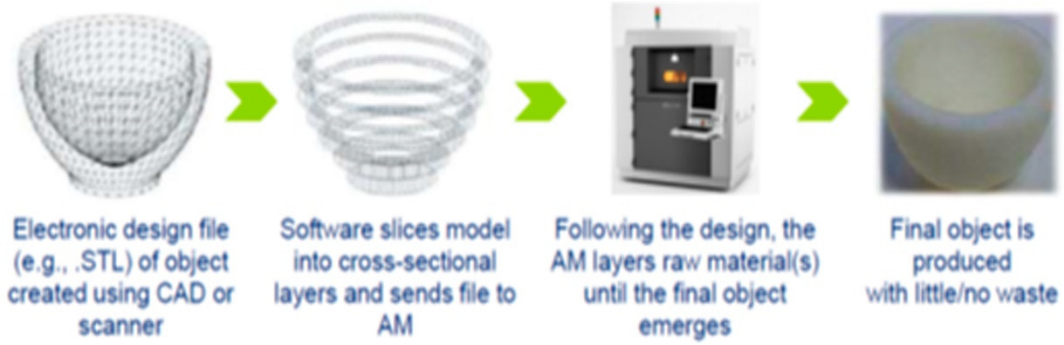

Figure 1 Additive Layer Manufacturing Technology Process Flow [2]

The ALM adoption timeline, the shift of ALM applications milestones in Aerospace and Defense industry [2], are as shown in Fig. 2.

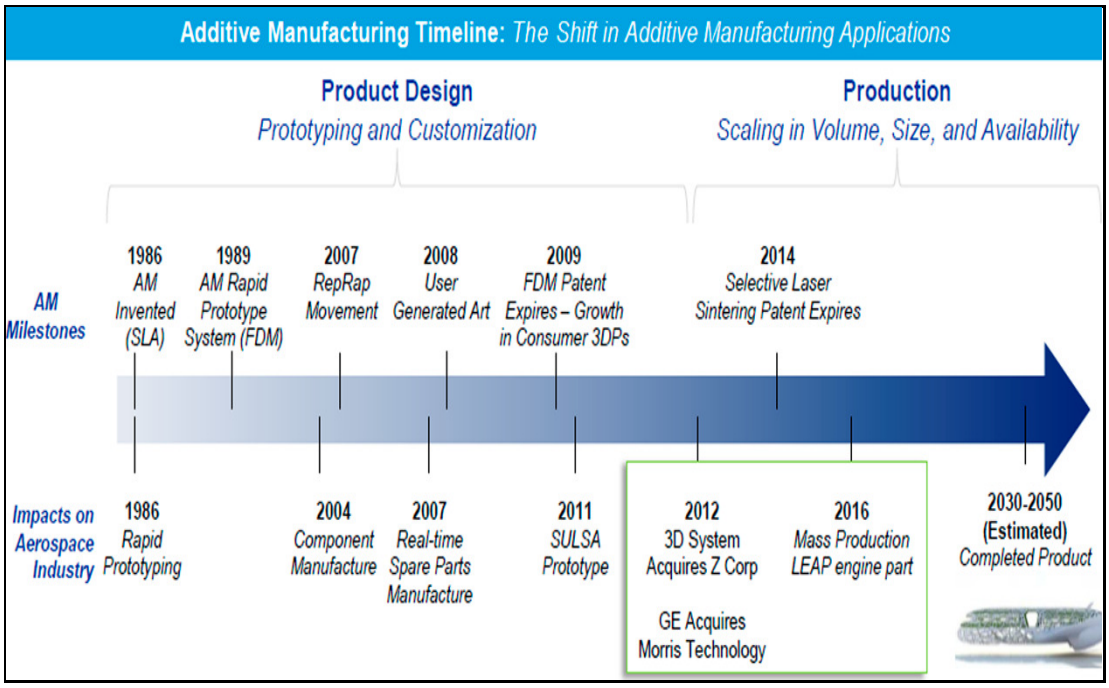

Figure 2 Additive Layer Manufacturing Technology Adoption Timeline [2]

The ALM Technology Readiness Levels (TRL) and impact on aerospace and defense industry [2], are as shown in a Table. 1.

Table 1 Additive Layer Manufacturing Technology Readiness Levels vs Timeline [2]

Timeline	ALM Technology Readiness Levels	ALM Milestones	Impact on Aerospace and Defense Supply Chain
1986	1	Stereolithography (SLA)	Rapid Prototyping
1989	1.5	Fused Deposition Modeling (FDM)	Rapid Prototype System
2004	2	-	Component Manufacture
2007	3	Replication Rapid-Prototype Project (RepRap) Movement	Real-time Spare Parts Manufacture
2008	3.5	User Generated Art	-
2009	3.5	FDM Patent Expires, Growth in Consumer 3DPs	-
2011	4	-	Southampton University Laser Sintered Aircraft (SULSA) Prototype
2012	4.5	-	3D System Acquires Z Corp. GE Acquires Morris Technology
2014	4.5	Selective Laser Sintering (SLS) Patent Expires	-
2016	5	-	Mass Production CFM LEAP Engine
2030	6	-	Completed Product
2040	6.5	-	Completed Product
2050	7	-	Completed Product

The ALM technology maturity curve, based on technology readiness levels vs timeline, is as shown in Fig. 3.

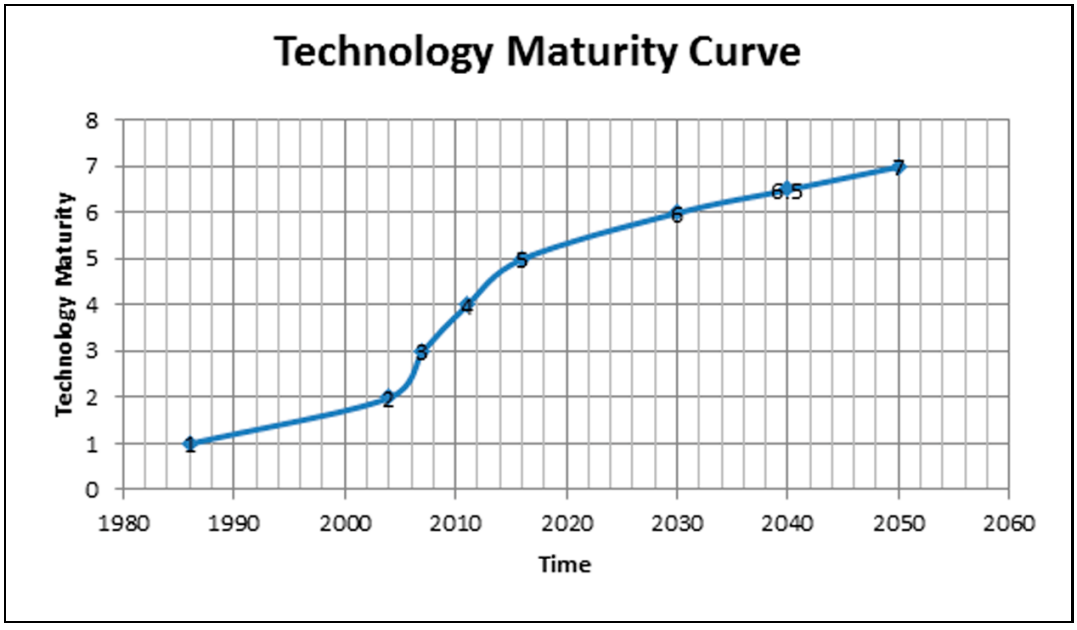

Figure 3 Additive Layer Manufacturing Technology Maturity Curve [2]

The ALM technology on Gartner's Emerging Technologies Hype Cycles [2], is as shown in Fig. 4.

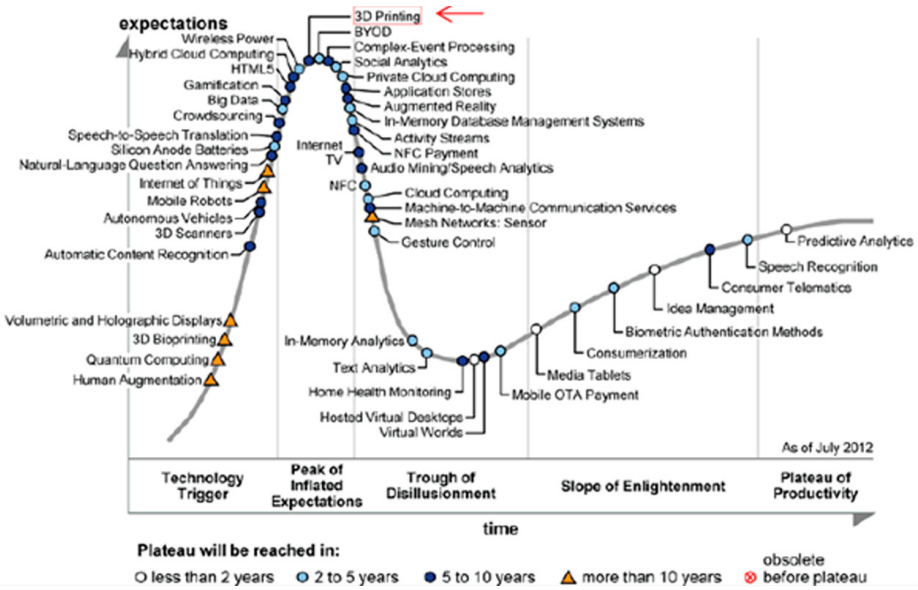

Figure 4 Additive Layer Manufacturing Technology on Gartner's Emerging Technologies Hype Cycle [2]

The global market size and forecast of ALM [2], is as shown in Fig. 5.

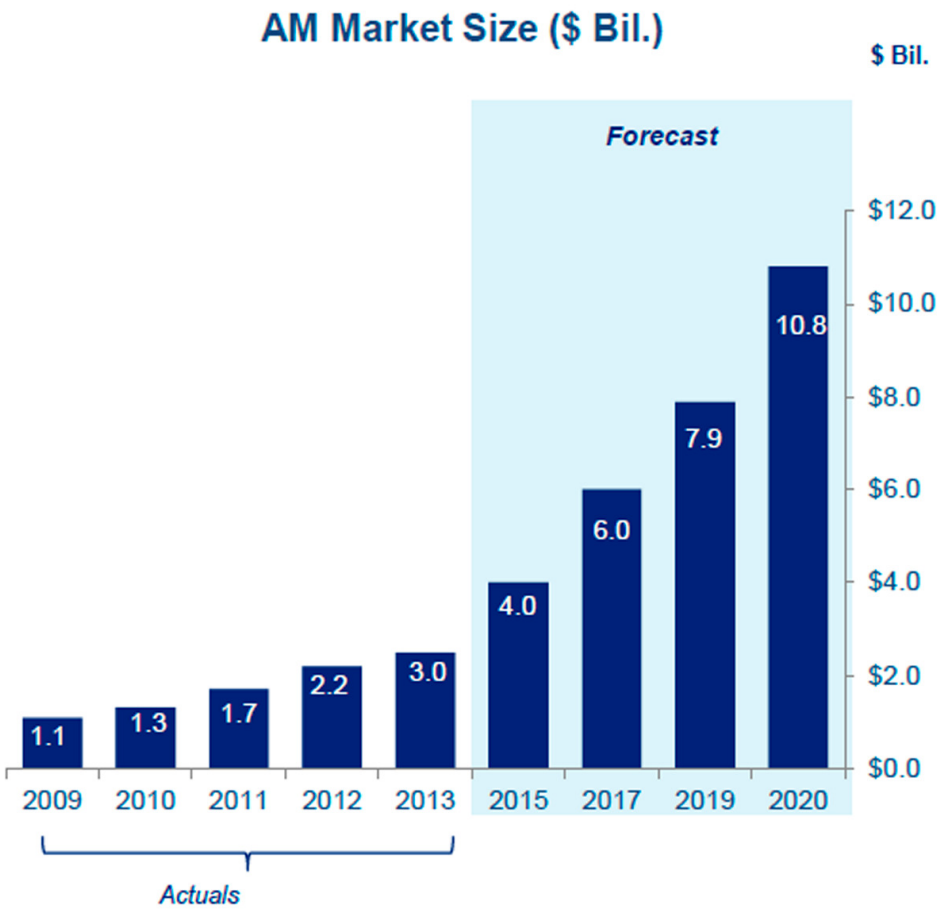

Figure 5 Additive Layer Manufacturing Technology Global Market Size and Forecast [2]

The main advantages of ALM in supply chain are [3], [4]: part costs down to ~50%, market costs down to ~64%, wastage down to ~10%, weight down to ~64%, and finally part buy to fly ratio is 1:1, are as shown in Fig. 6.

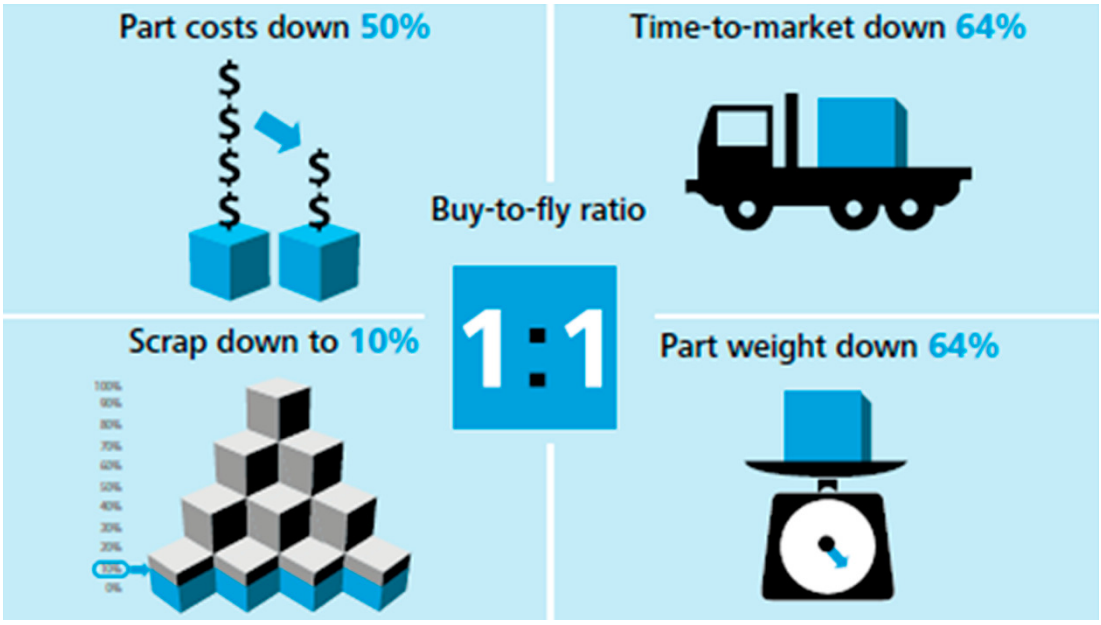

Figure 6 Additive Layer Manufacturing Technology Advantages [4]

The main challenges of ALM in supply chain are [5], [6], [7], [8], [9], [10]: limitation of size, limitation of scalability, limitation of material choice, high cost of material, issues of quality consistency, and limitation of multi-material printing capability.

The ALM projections from 2013 to 2023 for the aerospace and defense market [11], are as shown in a Table. 2.

Table 2 ALM Projection From 2013 to 2023 For The Aerospace and Defense Market [11]

Year	Optimistic	Pessimistic
2013	250	200
2015	375	225
2017	500	275
2019	750	300
2021	1250	400
2023	2000	500

The ALM projection from 2013 to 2023, especially with further acceptance of ALM technology for high volume parts in serial production [11], is as shown in Fig. 7.

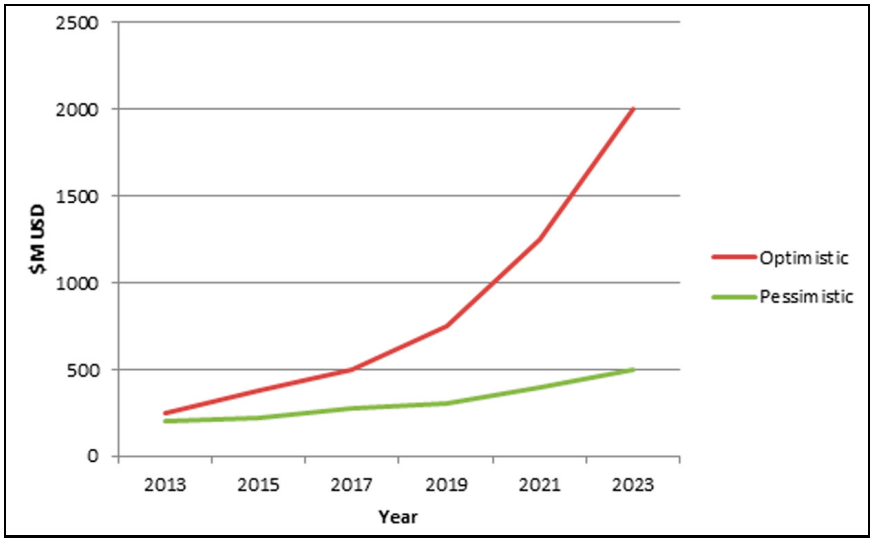

Figure 7 Additive Layer Manufacturing Technology Projection from 2013 to 2023 for Aerospace and Defense Market [11]

3. EXISTING AND POTENTIAL FUTURE STAKEHOLDERS IN ADDITIVE LAYER MANUFACTURING TECHNOLOGY

In 1980s, the ALM technology has into the market and witnessed significant growth in the last three decades.

Based on ALM capabilities, it provides significant growth opportunity for various industries such as aerospace, automotive, medical, consumer goods/electronics, industrial, academic, government, architectural and others.

The ALM market share of industrial stakeholders [12], is as shown in Fig. 8.

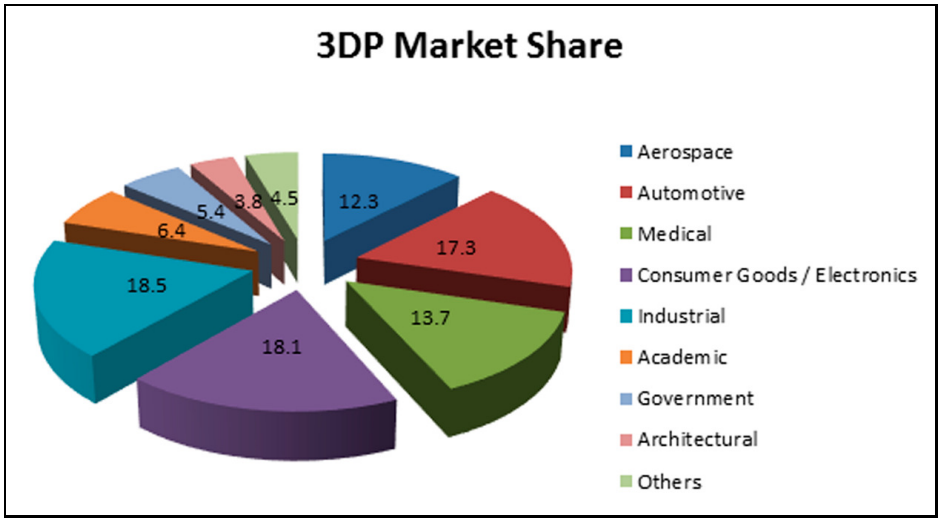

Figure 8 Additive Layer Manufacturing Technology Stakeholders [12]

The established key players in various industries are continue to explore their benefits and capturing their market share.

The existing key players in the 3DP market are: Stratasys Inc (United States) (Makerbot was acquired by Stratasys), 3D Systems Inc (United States) (Bits from Bytes, Z Corporation were acquired by 3D Systems), Concept Laser GmbH (Germany), Arcam AB (Sweden), Optomec (United States), EOS (Electro Optical Systems) GmbH (Germany), ExOne GmbH

(Germany), Materialise NV (Belgium), Object (Israel), Solidscape (United States), Envisiontec (Germany), Beijing Yinhua (China), Solido (Israel), DWS (Italy), DTM (United States), Helisys (United States).

According to Wohlers report [12], the largest regional market of ALM is North America in terms of market share, it is because of high development of ALM technology and existence of major players in this region. In North America, the major players of ALM are Stratasys and 3D Systems.

In the future, Europe and Asia-Pacific ALM markets are expected to grow rapidly. In the Asia-Pacific region, Japan will be the largest ALM market, due to favourable government policies for production and spending more on development of ALM technology. China will be the second largest ALM market, due to increase the budget from government and expected to focus on growth of the ALM market in the near future.

According to the forecast, the Europe ALM market is expected to supersede the North America ALM market by the end of 2020 and the estimated value to be USD 3,505.9 million.

Leading aerospace companies such as Airbus, Bombardier, Rolls-Royce, Snecma, and Avio Aero are currently investing in research and developing new ALM applications at a rapid pace.

The potential players in the ALM market are [13]: Stratasys, 3D Systems, Materialise, and ExOne.

4. KEY FACTORS INFLUENCING THE BUSINESS CASE OF ADDITIVE LAYER MANUFACTURING TECHNOLOGY ON AEROSPACE AND DEFENSE SUPPLY CHAIN

The overall influencing key benefits of ALM technology in various industries including aerospace, automotive, consumer and medical are [14]: improved structures and shapes, a new mixture of materials, reduced wastage, lowered manufacturing cost, reduced production lead-time, and reduced time to market.

The ALM market share of industry [13], is shown in Fig. 9.

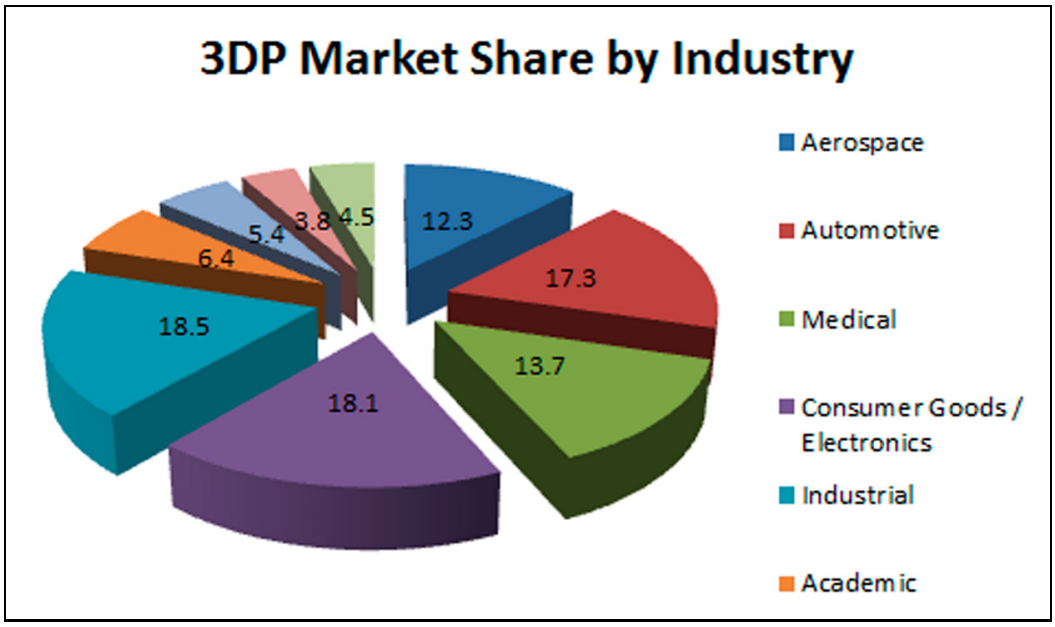

Figure 9 Additive Layer Manufacturing Technology Market Share by Industry [12]

The ALM market share of location [13], is shown in Fig. 10.

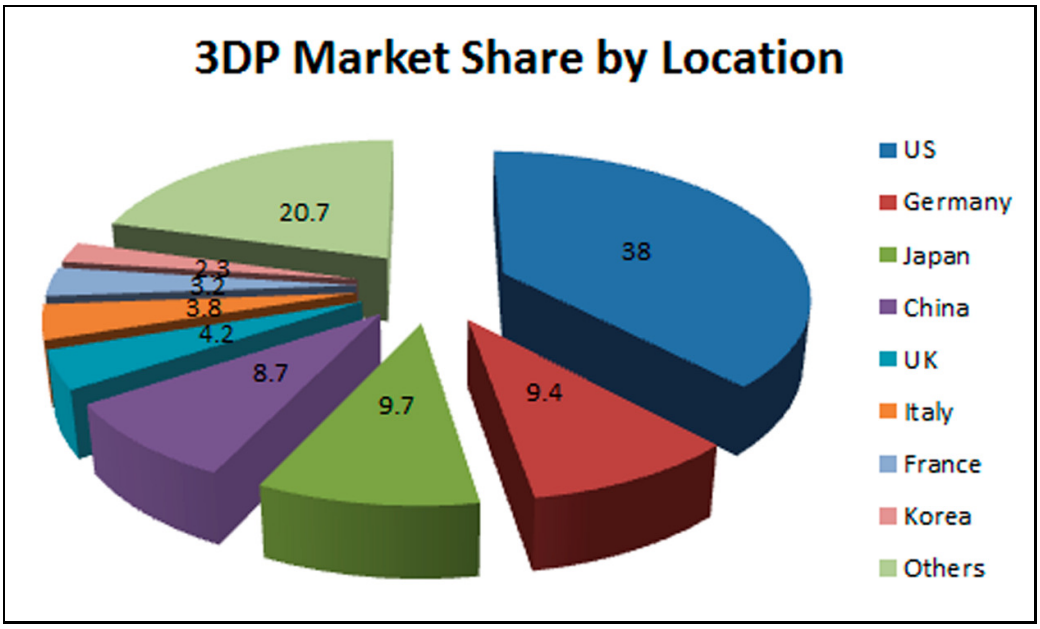

Figure 10 Additive Layer Manufacturing Technology Market Share by Location [13]

The ALM market share of region [13], is shown in Fig. 11.

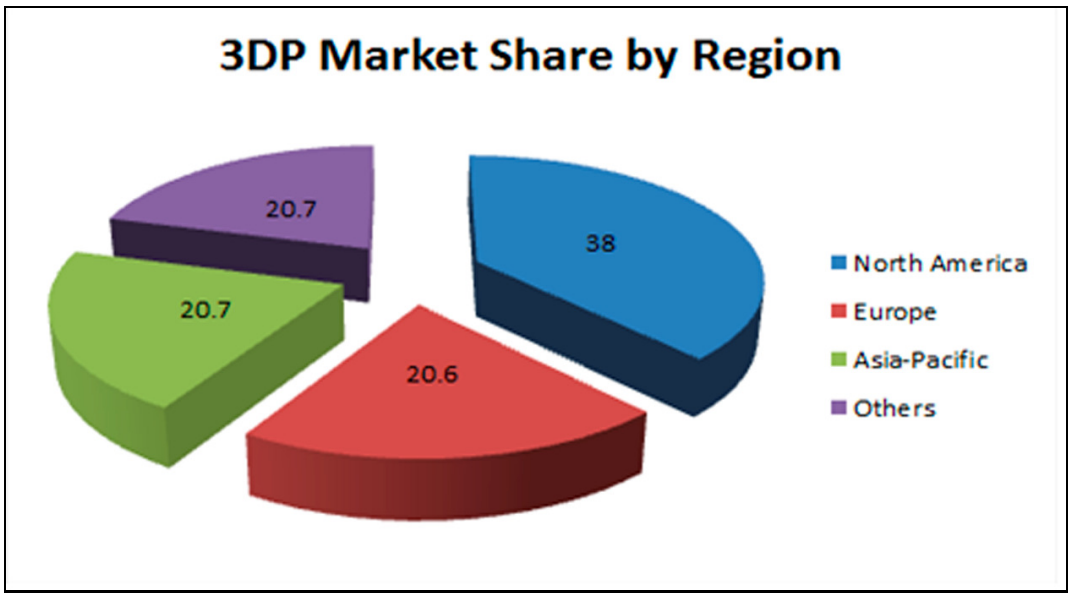

Figure 11 Additive Layer Manufacturing Technology Market Share by Region [13]

North America and Europe are the largest regional market of ALM with 38 and 20.6 percent of the ALM market share, the key factors are: high development of ALM technology, and the existence of major players in this region.

Asia-Pacific is the next largest regional market of ALM with 20.7 percent of the ALM market share, due to the following key factors: extensive industrial base and rapid growth, supportive government initiatives and policies, government funding in research & development.

5. KEY DRIVERS OF ADDITIVE LAYER MANUFACTURING TECHNOLOGY ON AEROSPACE AND DEFENSE SUPPLY CHAIN

The key drivers of ALM technology on Aerospace and Defense supply chain operations are [15], [16]: reduce cost, reduce weight, increase supply chain efficiency, improve fuel efficiency, reduce life cycle cost, optimize design, extend part life, increase material performance, increase material utilization, simplify the assembly process, and increase production efficiency.

6. TRENDS ON CHANGES IN SUPPLY CHAIN DUE TO ADDITIVE LAYER MANUFACTURING TECHNOLOGY

The major trends on changes in supply chain due to ALM technology [15], [16] are: reduce manufacturing lead time, short time to market, short time to meet customer demand, efficient use of materials, supply chain in remote locations, on-site spare parts, mobile additive center, local ability to grow parts, balance inventory with needs, and flexibility of design changes.

7. TRENDS ON CHANGES IN SUPPLY CHAIN DUE TO ADDITIVE LAYER MANUFACTURING TECHNOLOGY IN INDUSTRY SECTORS

The major aerospace and defense changes in supply chain due to ALM are: reduce part buy-to-fly ratio, reduce part weight, increase supply chain efficiency, improve fuel efficiency, reduce life cycle cost, increase production efficiency, simplify the assembly process, use materials more efficiently, shorter time to market, more quickly meet customer demand, reduce the waste material and reuse the leftover material, on demand print and eliminate the carry inventory, adoption of technologies, accelerating innovation, and new business models.

The major automotive changes in supply chain due to ALM are: reduce part weight, increase supply chain efficiency, increase part quality, reduce part cost, increase production efficiency, increase part reliability, increase part reproducibility, increase part recyclability, and flexibility of design changes.

The major-medical changes in supply chain due to ALM are: increase device customization, device personalization, increase supply chain efficiency, increase device safety, reduce health risks, increase the device life, reduce the device size, and quick response time.

The major consumer goods and electronics changes in supply chain due to ALM are: customize product, increase supply chain efficiency, increase functionality, enhance materials, sustain raw materials, more colorful items, innovate the product, design freedom, reduce cost, and multiple functionalities.

8. CASE STUDIES OF ADDITIVE LAYER MANUFACTURING TECHNOLOGY ON AEROSPACE AND DEFENSE SUPPLY CHAIN

8.1. Case Study 1: Additive Layer Manufacturing of Aerospace Brackets

ALM technology based Joint Strike Fighter Beed Air Leak Detect Bracket [17], is as shown in Fig. 12.

Figure 12 Additive Layer Manufacturing Technology Aerospace Brackets – Joint Strike Fighter Bleed Air Leak Detect Bracket [17]

8.2. Case Study 2: Additive Layer Manufacturing of Aerospace Propellant Tank

ALM technology based Titanium Propellant Tank [18], is as shown in Fig. 13.

Figure 13. Additive Layer Manufacturing Technology Aerospace Propellant Tank - Titanium Propellant Tank [18]

8.3. Case Study 3: Additive Layer Manufacturing of Aerospace Engine Parts

ALM technology based Tejas Kaveri Engine Parts [19], are as shown in Fig. 14.

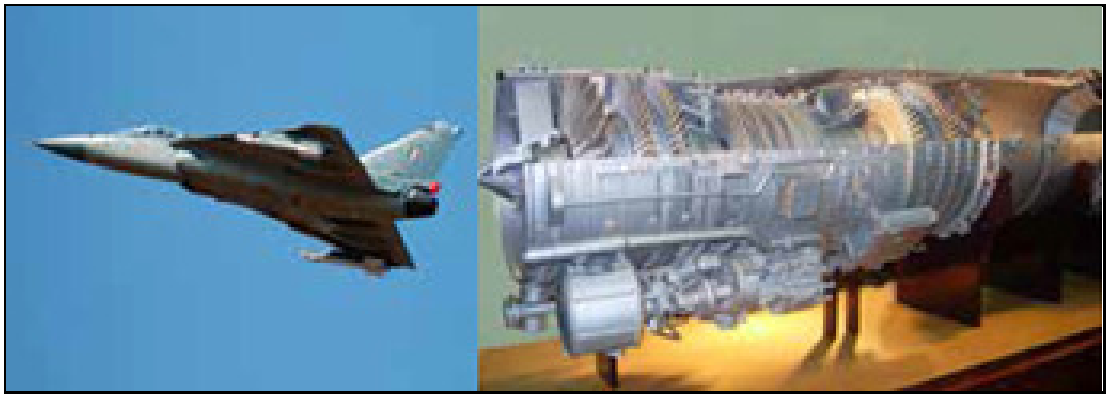

Figure 14 Additive Layer Manufacturing Technology Aerospace Engine Parts – Tejas Kaveri Engine Parts [19].

8.4. Case Study 4: Additive Layer Manufacturing of Aerospace Fuel Nozzle

ALM technology based GE LEAP Jet Engine Fuel Nozzle [20], is as shown in Fig. 15.

Figure 15 Additive Layer Manufacturing Technology Aerospace Fuel Nozzle – GE LEAP Jet Engine Fuel Nozzle [20]

The major implications and challenges of early adopters of ALM technology are [21], [22]: technical implications, legal issues, financial implications, political issues, government challenges, supply chain implications, human resource implications, software implications, dangerous weapons, and security challenges.

9. THE COMPETITOR FOOTPRINT AND ITS EXTENT OF ADOPTION OF ADDITIVE LAYER MANUFACTURING TECHNOLOGY IN AEROSPACE AND DEFENSE INDUSTRY

The leading aerospace manufacturers in the ALM technology production are [23], [24]: Airbus, Boeing, GE Aviation, Lockheed Martin, Rolls-Royce, Honeywell, and Pratt & Whitney.

The most significant adoption of ALM technology drivers are [25]: mass production, improve process, new product, incorporate energy, create new structures, new government initiatives, and public private partnerships.

The main challenges to use of ALM technology are: standards, material selection, material cost, and processes.

10. SWOT ANALYSIS AND INDICATORS OF FUTURE GROWTH

The SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis performed based on the impact of ALM technologies on aerospace and defense supply chain, is as shown in Fig. 16.

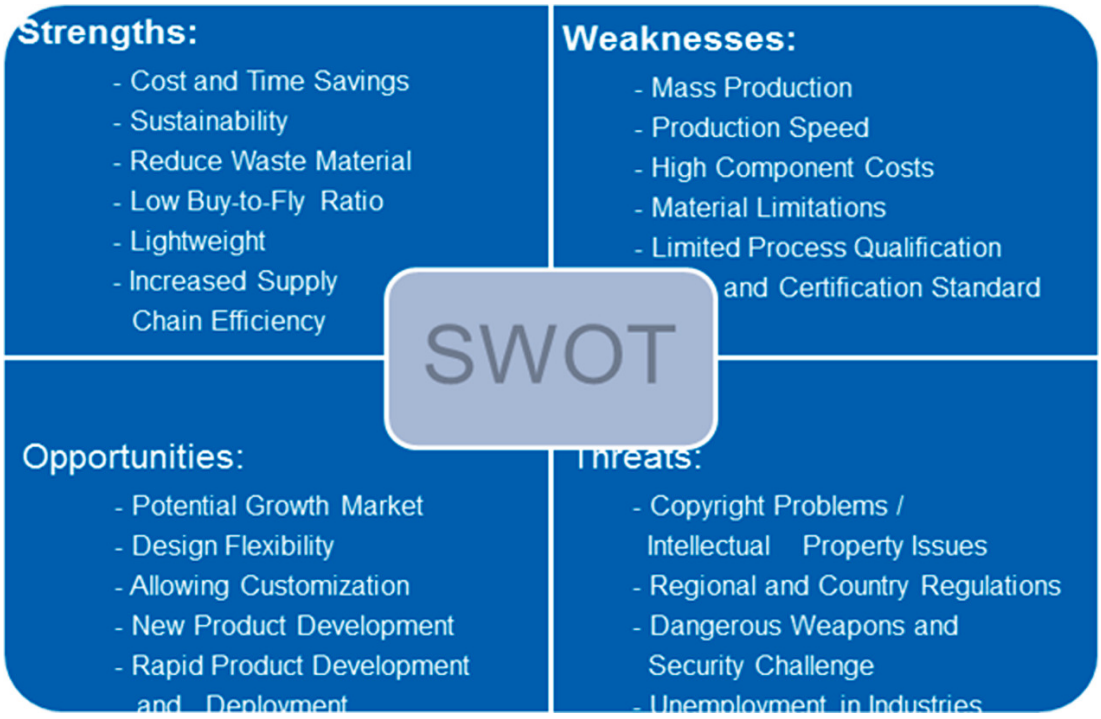

Figure 16. Additive Layer Manufacturing Technology - SWOT Analysis

The strengths of ALM technologies are: reduce cost, save time, sustainability, reduce waste material, low buy-to-fly ratio, reduce weight, increased supply chain efficiency.

The weaknesses of ALM technologies are: mass production, production speed, high component costs, material limitations, limited process qualification and certification standards.

The opportunities of ALM technologies are: potential growth market, design flexibility, allowing customization, new product development, rapid product development and deployment.

The threats of ALM technologies are: copyright problems, intellectual property issues, regional and country regulations, dangerous weapons and security challenge, unemployment in industries.

The ALM technology worldwide revenue gradually increases from 1993 to 2011, especially with ALM technology products and services [26], [27], [28], [29], is as shown in Fig. 17.

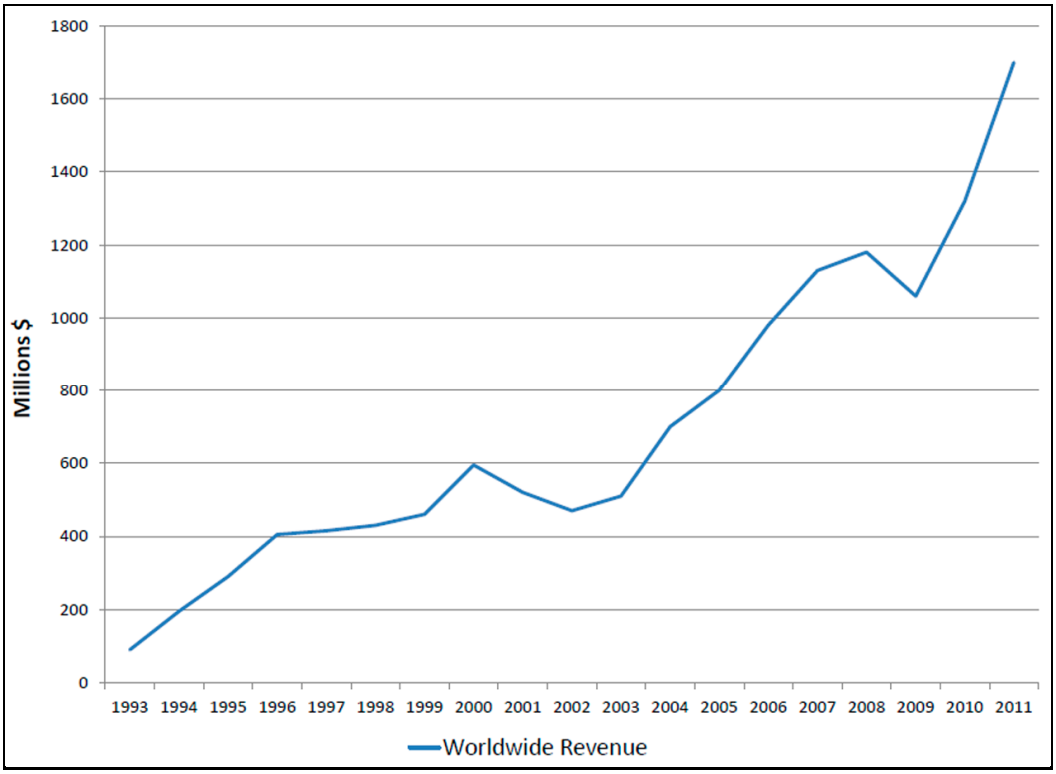

Figure 17. Additive Layer Manufacturing Technology Products and Services - Worldwide Revenue [29]

The ALM technology breakeven analysis [30], is as shown in Fig. 18.

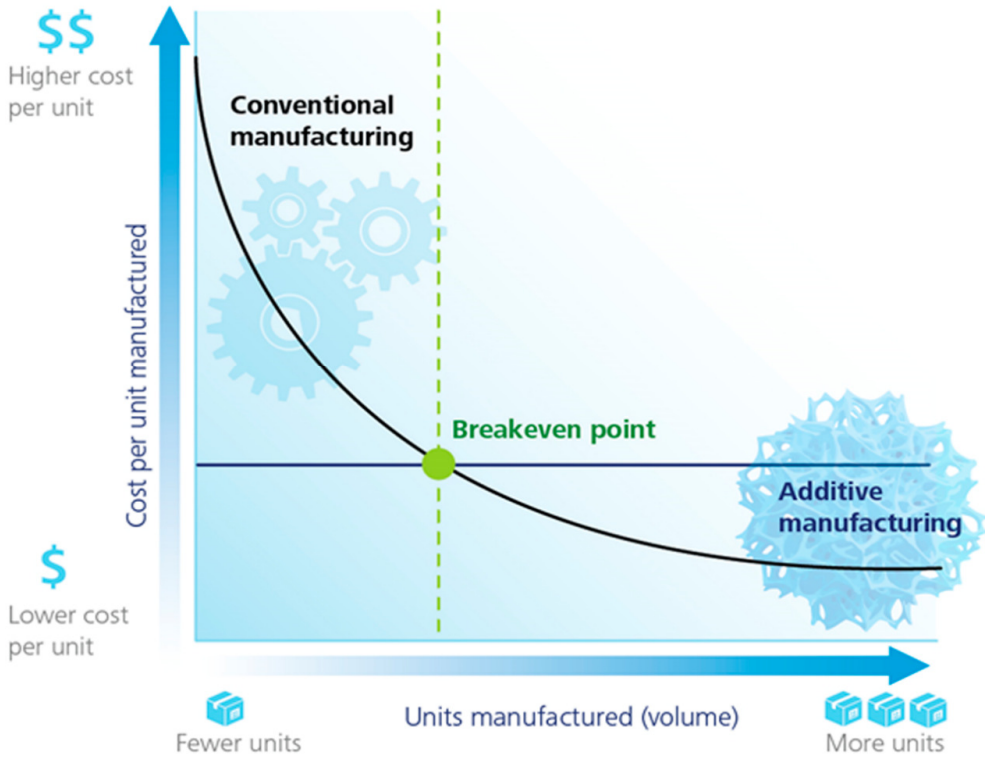

Figure 18. Additive Layer Manufacturing Technology Breakeven Analysis [30]

The significant indicators of likely continuing growth in ALM technology are as follows: advances in materials, new design tools, and expiration of key patents.

11. CONCLUSIONS

The overall conclusion is that ALM technology offers some strengths as well as weaknesses and it depends on the specific requirements of whether the weak or strong points outweigh each other. The strengths of ALM technologies are: reduce cost, save time, sustainability, reduce waste material, low buy-to-fly ratio, reduce weight, increased supply chain efficiency. The weaknesses of ALM technologies are: mass production, production speed, high component costs, material limitations, limited process qualification and certification standards. The opportunities of ALM technologies are: potential growth market, design flexibility, allowing customization, new product development, rapid product development and deployment. The threats of ALM technologies are: copyright problems, intellectual property issues, regional and country regulations, dangerous weapons and security challenge, unemployment in industries. At present, North America and Europe are the largest regional market of ALM technology. Asia-Pacific is the next largest regional market of ALM technology. The expansion and global distribution of ALM is still in its early stages and will increase over the next few years. Thereby industrial use will increase in importance and will change or replace whole industries.

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